

A Method of Measuring the Pressure Produced in the Detonation of High Explosives or by the Impact of Bullets.

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(Received October 17,—Read November 27, 1913.)

(Abstract.)

If a rifle bullet be fired against the end of a cylindrical steel rod, or some gun-cotton be detonated in its neighbourhood, a wave of pressure is transmitted along the rod with the velocity of sound. If the pressure in different sections of the rod be plotted at any instant of time, the abscissæ being distances along the rod, then at a later time the same curve shifted through a distance proportional to the time will represent the then distribution of pressure. Also the same curve represents the relation between the pressure across any section of the rod and the time, the scale of time being approximately 2 inches for 10^{-5} seconds. In particular it represents the relation between the total pressure applied to the end of the rod and the time, and the length of the curve represents the total duration of the blow.

If the rod be divided at a point a few inches from the far end, the opposed surfaces of the cut being in firm contact and carefully faced, the wave of pressure travels practically unchanged through the joint. At the free end it is reflected as a wave of tension, and the pressure at any section is then to be obtained by adding the effects of the pressure wave and the tension wave. At the joint the pressure continues to act until the head of the reflected tension wave arrives there. If the tail of the pressure wave has then passed the joint the end-piece flies off, having trapped within it the whole of the momentum of the blow, and the rest of the rod is left completely at rest. The length of end-piece which is just sufficient completely to stop the rod is half the length of the pressure wave, and the duration of the blow is twice the time taken by the pressure wave to travel the length of the end-piece. Further, it is easy to see, as is proved in detail in the paper, that the momentum trapped in quite short end-pieces will be equal to the maximum pressure multiplied by twice the time taken by the wave in traversing the end-piece. Thus by experimenting with different lengths of end-pieces and determining the momentum with which each flies off the rod as the result of the blow it is possible to measure both the duration of the blow and the maximum pressure developed by it. This is the basis of the experimental method described in the paper. A steel rod is hung up as a ballistic pendulum, and the piece is held on to the end by magnetic attraction.

A bullet is fired at the other end, and the end-piece is caught in a ballistic pendulum and its momentum measured. The momentum of the rod is also measured.

Most of the experiments described in the paper were made with lead bullets with the object of checking the accuracy of the method. On the assumption that a lead bullet behaves on impact as a fluid the time taken completely to stop it, which is the duration of the blow, is equal to the time which it takes to travel its own length, and the maximum pressure is equal to the mass per unit of length in the section of greatest area multiplied by the square of the velocity. The experiments showed good agreement between the observed and calculated values of the maximum pressure as is shown in the following table:—

Velocity of bullet.	Maximum pressure.	
	Calculated.	Observed.
ft./sec.	lb.	lb.
2000	43,500	42,600
1240	15,700	16,700
700	5,450	5,320

The observed duration of the blow is in the case of the highest velocity about 6 per cent. greater than the time taken by the bullet to travel its own length. This discrepancy is to be accounted for partly by the fact that the bullet is really not absolutely fluid, but is also in part due to the non-fulfilment of some of the conditions postulated in the simple theory of the method. It seems probable that the principal source of error of the latter kind is that the pressure applied by the bullet is not uniformly distributed over the end. Experiments with rods of different diameter show that the larger ones give larger estimates of the duration of the impact.

Having established by experiments on lead bullets that the method of experiment is capable of giving within a few per cent. both the maximum pressure and the duration of very violent blows, experiments were next made on the detonation of gun-cotton. Cylinders of dry gun-cotton $1\frac{1}{4}$ inch \times $1\frac{1}{4}$ inch and weighing about 1 oz. were detonated with fulminate at a distance of about $\frac{3}{4}$ inch from the end of the steel rod. The results may be expressed by saying that the average value of the pressure during a period of 10^{-5} seconds in the neighbourhood of the maximum is about thirty tons per square inch. The absolute maximum is of course considerably higher. The pressure has practically disappeared in $1/50,000$ second,

that is at least 80 per cent. of the impulse of the blow has been delivered within that time. Experiments were also made with gun-cotton in contact with the rod, but owing to the permanent deformation of the steel, which would have the effect of deadening the blow, the results in this case cannot claim to be precise. They lead, however, to the conclusion that the maximum pressure at the surface of contact is at least double what it is when an air-space $\frac{3}{4}$ inch thick is interposed.

The results obtained for gun-cotton, though lacking in precision, throw some light on the nature of the fracture which is produced by the detonation of this explosive in contact with a mild steel plate. They show that the pressure of the gun-cotton may be regarded as an impulsive force in the sense that only very small displacement of the steel occurs during its action. Its effect is to give velocity to the parts of the plate with which it is in contact, the remainder being left at rest. In a plate 1 inch thick the velocity given by a slab of gun-cotton of about the same thickness is roughly 200 feet per second. The resulting strain depends upon the ratio of this velocity to the velocity of propagation of waves of stress into the material, and, assuming perfect elasticity, shearing stresses of the order of 100 tons per square inch may be produced in a plate of this thickness. In static tests on mild steel the metal flows when the shearing stress is of the order of 10 tons per square inch, and no materially greater stress can exist. But if the rate of straining is sufficient, the viscosity of the flowing metal becomes important, and the shearing stress may approximate to the value corresponding to perfect elasticity. The shearing stress is accompanied by tension, which under such circumstances may be sufficient to break down the forces of cohesion. Thus the steel is cracked in spite of its ductility, just as pitch may be cracked by the blow of a hammer. From the measured duration of the pressure produced by gun-cotton it may be inferred that the velocity of shear required to crack mild steel is of the order of 1000 radians per second.

The shattering of the plate by the gun-cotton probably occurs during the time that the pressure is acting—that is within two or three hundred-thousandths of a second—and before the plate has had time to be sensibly deformed. The bending of the broken pieces, which is always found when mild steel is broken in this way, occurs subsequently, and is due to the relative velocities which remain in the different parts of each piece of the plate after the plate has been broken and the pressure has ceased to act.
